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TECHNICAL MEMORANDUM

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SKIN AND STRUCTURAL TEMPERATURES MEASURED ON THE X-15 AIRPLANE DURING A FLIGHT TO A MACH NUMBER OF 3.3

By Robert D. Reed and Joe D. Watts

Flight Research Center
Edwards, Calif.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL MEMORANDUM X-468

SKIN AND STRUCTURAL TEMPERATURES MEASURED ON THE X-15 AIRPLANE DURING A FLIGHT TO A MACH NUMBER OF 3.3*

By Robert D. Reed and Joe D. Watts

SUMMARY

A survey of skin and structural temperatures was obtained on the X-15 airplane during a flight to a Mach number of 3.3. Fuselage, wing, horizontal-tail, and vertical-tail temperatures are presented to show temperature variations on the external surfaces and temperature differences between the skin and internal structure.

The maximum temperature recorded was 440° F on an unsupported skin area on the lower vertical tail.

Temperature differences of 400° F were recorded between the external skin and internal spar webs on the wing. Local external temperature differences caused by the heat-sink effect of the supporting structure were as great as 220° F.

Temperature-indicating paint aided in identifying the location of areas of concentrated heating on the lower surface of the wing.

INTRODUCTION

Because of the importance of the aerodynamic-heating problem during high-speed flight, extensive analytical studies on the subject, as well as wind-tunnel and free-flight model testing, have been conducted. In the final analysis, however, aerodynamic-heating data from full-scale flight tests provide the only positive basis for evaluating the methods of analysis and for determining the extent to which model tests accurately simulate actual flight.

*Title, Unclassified.

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A major objective of the flight research program being conducted with the X-15 airplane at the NASA Flight Research Center, Edwards, Calif., is the study of aerodynamic heating. Thus, the X-15 was instrumented with 578 chromel-alumel thermocouples to provide temperature measurements on external skin and internal structure.

The X-15 flight program is separated into two basic phases: the interim-engine phase and the design-engine phase. The maximum Mach number obtainable with the interim configuration is approximately 3.3, whereas the maximum predicted Mach number for the design configuration is about 6.0.

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During the complete program planned with the design engine, heat-transfer data will be collected and compared with calculated data. However, because of the current interest in actual temperatures measured in high-speed flight, this paper presents only recorded temperatures with no heat-transfer analysis.

AIRPLANE

The X-15 is a single-place rocket-propelled research airplane designed to explore the problems of aerodynamic heating and other problems associated with flight to an altitude of about 250,000 feet and to a Mach number of about 6.0. A photograph and three-view drawing of the X-15 are shown in figures 1 and 2, respectively. Some physical characteristics of the airplane are given in table I.

The entire skin of the X-15 is Inconel X, and the materials used in the internal structure are titanium alloys. Through the use of these materials, the airplane was built to withstand skin temperatures approaching 1,200° F.

The leading edges of the wing and tail surfaces were designed as heat sinks. The wing and vertical-tail leading-edge areas are thick Inconel X fittings machined from bar stock. The leading edge of the horizontal tail is formed of sheet stock, and the inside is filled with weld material to serve as the heat sink. The chordwise thicknesses of these heat-sink leading-edge areas are 0.688 inch on the wing and 0.125 inch on the tail surfaces. The radius of the wing leading edge is 0.375 inch, and that of the upper and lower vertical tails is 0.500 inch. The leading-edge radius of the horizontal tail varies from 0.500 inch at the root to 0.250 inch at the tip. The leading edges of the wing and tail surfaces are segmented to allow for thermal expansion. The gaps are approximately 0.050-inch wide. The materials and the thicknesses of the various skin areas and supporting structure of the X-15 are given in table II.

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Reaction-control nozzles, which are 1.40-inch holes flush with the skin, are located in the nose area of the fuselage and in the wings. These nozzles have a relatively high heat capacity and cause local heat-sink effects in the skin.

INSTRUMENTATION

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The temperature data presented in this paper were obtained from chromel-alumel thermocouples which are a part of the permanent instrumentation of the X-15 airplane. The number of thermocouples located in the different structural components of the airplane and the number of representative thermocouples from which data were obtained for this paper are given in table III.

The overall accuracy of the temperature data, including the error of the thermocouple recording system and data-reduction error, is estimated to be ±1.0 percent.

A temperature-indicating paint was used on the lower surface of the left wing to give indications of high-temperature areas. The paint used, which is sold under the label "DetectoTemp", was procured from the Curtiss-Wright Corp., Princeton Division. The temperatures at which the color transitions occur vary with heating time; therefore, the paint indications were used only as qualitative data. A detailed description of the use of temperature-sensitive paint to obtain qualitative aerodynamic heat-transfer data is presented in reference 1.

RESULTS AND DISCUSSION

Temperatures of all major structural components of the X-15 airframe except the uninstrumented jettisonable lower vertical tail are presented in this paper. The temperature data are given in two basic forms: as time histories at representative skin locations and as temperature distributions for all major structural components at or near the time of maximum skin temperature.

The time history of the flight from which these measurements were obtained is shown in figure 3. Presented are the variation with time of altitude, Mach number, angle of attack, stagnation temperature, and dynamic pressure. The maximum Mach number of 3.3 was attained during a dive from an altitude of about 80,000 feet.

Time histories of representative temperatures on unsupported skin areas most sensitive to aerodynamic heating for each major component of the X-15 are shown in figure 4. The highest temperature, 440° F, was recorded on the fixed portion of the lower vertical tail. Peak

skin temperatures occurred about 308 seconds after the reference zero time, which was a few seconds before launch. In order to present a common basis of comparison of temperature distributions, the following discussion will pertain only to the temperatures experienced by the various components at time 308 seconds.

Fuselage

A considerable variation of temperature occurred along the fuselage between the nose and the tail. Figure 5 shows the distribution of skin temperatures along the bottom of the fuselage. The maximum temperature on the bottom, 390° F, was recorded under the cockpit. The minimum temperature of -170° F which occurred at the midsection is attributed to the very low temperature of the liquid oxygen stored in this portion of the fuselage.

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Figure 6 shows a cross section of the fuselage and the temperature distribution at about 58-percent fuselage length. At this fuselage location the cylindrical portion of the fuselage shows little variation in temperature around its circumference, while the outboard area of the side fairing shows a difference of about 130° F between the upper and lower skins. A uniform circumferential distribution of skin temperatures was found around the fuselage forward of the cockpit.

Wing

The wing skin temperatures differed considerably between the upper and lower surfaces, with the higher values recorded on the lower surface. Figure 7 shows that this difference was about 120° F at the root and midsemispan and about 50° F at the tip.

Figures 7(a) to 7(c) illustrate the effect of heat sinks on the external surface temperatures. For example, in figure 7(b) a difference of about 220° F exists between the unsupported skin and the spar cap on the bottom surface near the 25-percent chord. The heat-sink capacity of the leading edge is reflected in figure 7, in that the leading-edge temperatures are generally lower than the remaining forward portion of the wing. It is also seen in this figure that a temperature difference between the skin and spar webs ranging from 120° F to 400° F occurs at the time of peak temperatures.

Areas of concentrated heating on the lower surface of the wing are identified by the temperature-indicating paint, as shown in figure 8. The dark, wedge-shaped patterns that were retained in the paint indicate areas where relatively high maximum temperatures occurred. The wedge-shaped patterns probably resulted from turbulent

flow within the wedges. This would indicate that turbulence was induced in the flow by the leading-edge expansion joints and the reaction-control nozzle.

Figure 9 shows the spanwise variation of temperature on the leading edge of the wing. Measured thermocouple data show little variation; however, the paint patterns indicated that temperature discontinuities occurred at the expansion joints.

H209

Horizontal Tail

Figure 10 shows a chordwise distribution of the temperatures at a midsemispan station on the horizontal tail. The temperatures on the horizontal tail are similar in magnitude to the temperatures on the wing tip (fig. 7(c)) except that the top-surface temperature of the tail is about 30° F higher than the bottom-surface temperature. This trend is the reverse of that observed on the wing and results principally from the negative angle of attack of the horizontal tail during the heating phase of the flight. A significant drop in skin temperature occurred at the forward spar because of its high heat-sink capacity.

Vertical Tail

Temperatures on only one side of the vertical tails are shown (figs. 11 and 12) because of the symmetry of the temperatures measured.

A chordwise survey of temperatures on the movable upper vertical tail is shown in figure 11. The leading-edge fitting has a relatively high heat-sink capacity; therefore, the temperature on the leading edge is lower than on the remaining portion of the vertical tail. The general level of skin temperatures is about 380° F.

A chordwise survey of temperatures on the fixed lower vertical tail is shown in figure 12. The temperature characteristics are similar to those of the upper vertical tail except that the general level is higher. Also, the temperatures toward the rear are considerably lower than on the forward portions, primarily because of the thicker skin of the speed brakes. The overall maximum temperature recorded in the flight (440° F) occurred at about 50-percent chord on the fixed lower vertical tail.

CONCLUDING REMARKS

The following observations were made after examination of the temperatures encountered on the X-15 airplane skin and internal structure during a flight to a Mach number of about 3.3:

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1. The maximum temperature recorded was 440° F on an unsupported skin area on the lower vertical tail.

2. Temperature differences of 400° F between the external skin and internal spar webs were recorded on the wing.

3. Local external-surface temperature differences of as much as 220° F were encountered on the bottom surface of the wing.

4. Temperature-indicating paint helped to identify the locations of concentrated heating areas on the lower surface of the wing.

H209

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., November 21, 1960.

REFERENCE

1. Stainback, P. Calvin: A Visual Technique for Determining Qualitative Aerodynamic Heating Rates on Complex Configurations. NASA TN D-385, 1960.

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TABLE I.- PHYSICAL CHARACTERISTICS OF THE AIRPLANE

Wing:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 94.98 sq ft covered by fuselage), sq ft	200
Span, ft	22.36
Mean aerodynamic chord, ft	10.27
Root chord, ft	14.91
Tip chord, ft	2.98
Taper ratio	0.20
Aspect ratio	2.50
Sweep at 25-percent-chord line, deg	25.64
Incidence, deg	0
Horizontal tail:	
Airfoil section	NACA 66005 (Modified)
Total area (includes 63.29 sq ft covered by fuselage), sq ft	115.34
Span, ft	18.08
Mean aerodynamic chord, ft	7.05
Root chord, ft	10.22
Tip chord, ft	2.11
Taper ratio	0.21
Aspect ratio	2.83
Sweep at 25-percent-chord line, deg	45
Ratio horizontal-tail area to wing area	0.58
Upper vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	40.91
Span, ft	4.58
Mean aerodynamic chord, ft	8.95
Root chord, ft	10.21
Tip chord, ft	7.56
Taper ratio	0.74
Aspect ratio	0.51
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.20
Lower vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	34.41
Span, ft	3.83
Mean aerodynamic chord, ft	9.17
Root chord, ft	10.21
Tip chord, ft	8
Taper ratio	0.78
Aspect ratio	0.43
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.17
Fuselage:	
Length, ft	50.75
Maximum width, ft	7.33
Maximum depth, ft	4.67
Maximum depth over canopy, ft	4.97
Side area (total), sq ft	215.66
Fineness ratio	10.91

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TABLE II.- X-15 MATERIAL THICKNESSES AT TEMPERATURE-MEASURING LOCATIONS

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Component	Material	Thickness, in.
Wing		
Skin	Inconel X	0.040 to 0.088
Spar caps	Titanium alloy	0.040 to 0.080
Spar webs	Titanium alloy	0.020 to 0.050
Horizontal tail		
Skin	Inconel X	0.050
Main spar caps	Titanium alloy	0.309
Main spar webs	Titanium alloy	0.032
Upper and lower vertical tails		
Skin	Inconel X	0.020 to 0.100
Spar caps	Titanium alloy	0.020 to 0.108
Spar webs	Titanium alloy	0.020 to 0.025
Speed-brake skin	Inconel X	0.086 to 0.131
Fuselage		
Skin	Inconel X	0.050 to 0.136
Side fairing		
Skin	Inconel X	0.032 to 0.045

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TABLE III.- DISTRIBUTION OF THERMOCOUPLES IN THE X-15 AIRPLANE

Airplane components	Thermocouples			
	Skin		Internal structure	
	Installed	Used	Installed	Used
Fuselage and side fairing	127	35	110	0
Wing	128	98	45	25
Horizontal tail	47	24	16	5
Upper vertical tail	66	18	17	8
Lower vertical tail	18	17	4	4

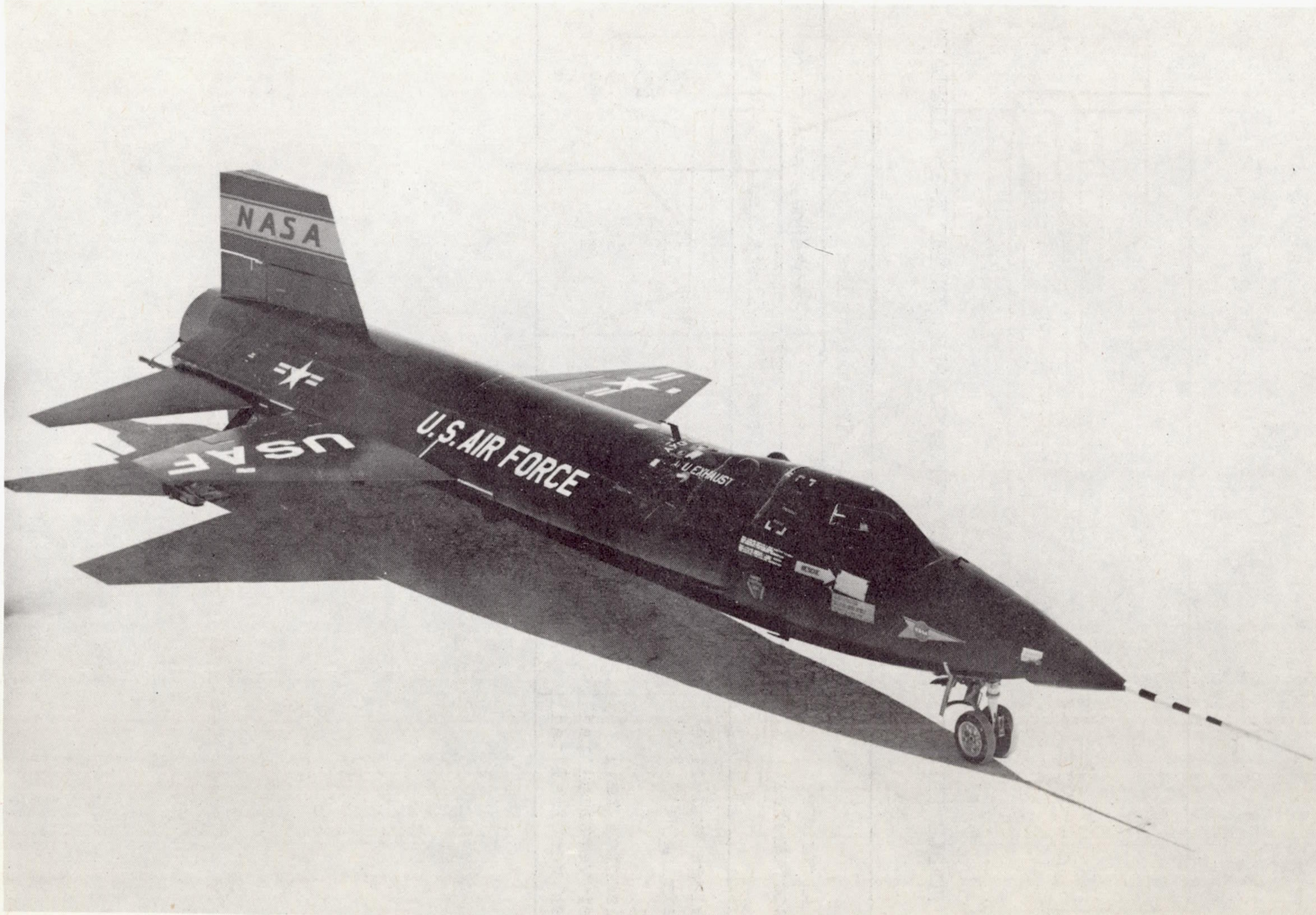

Figure 1.- X-15 research airplane. E-5250

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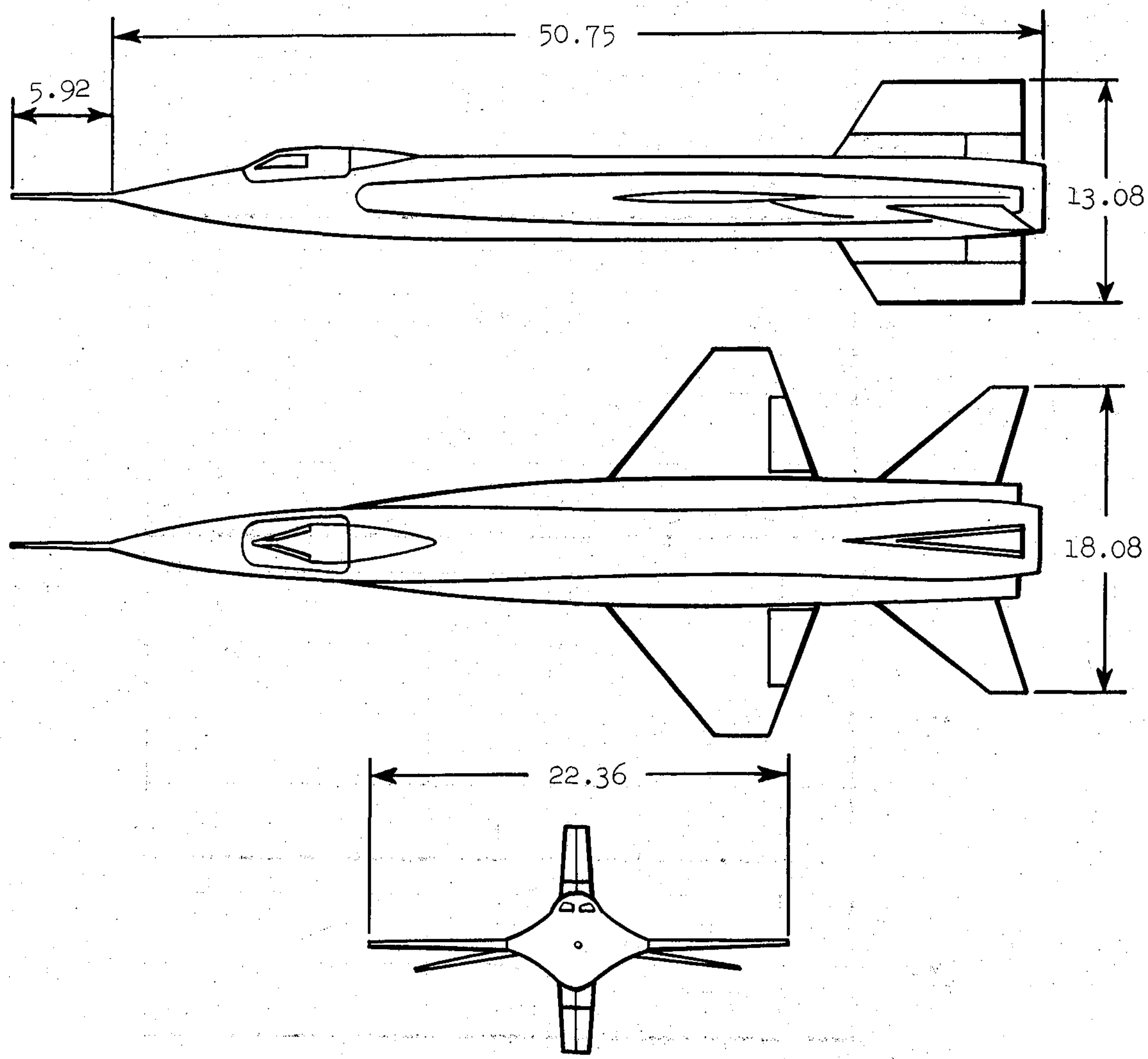

Figure 2.- Three-view drawing of the X-15 airplane. All dimensions in feet.

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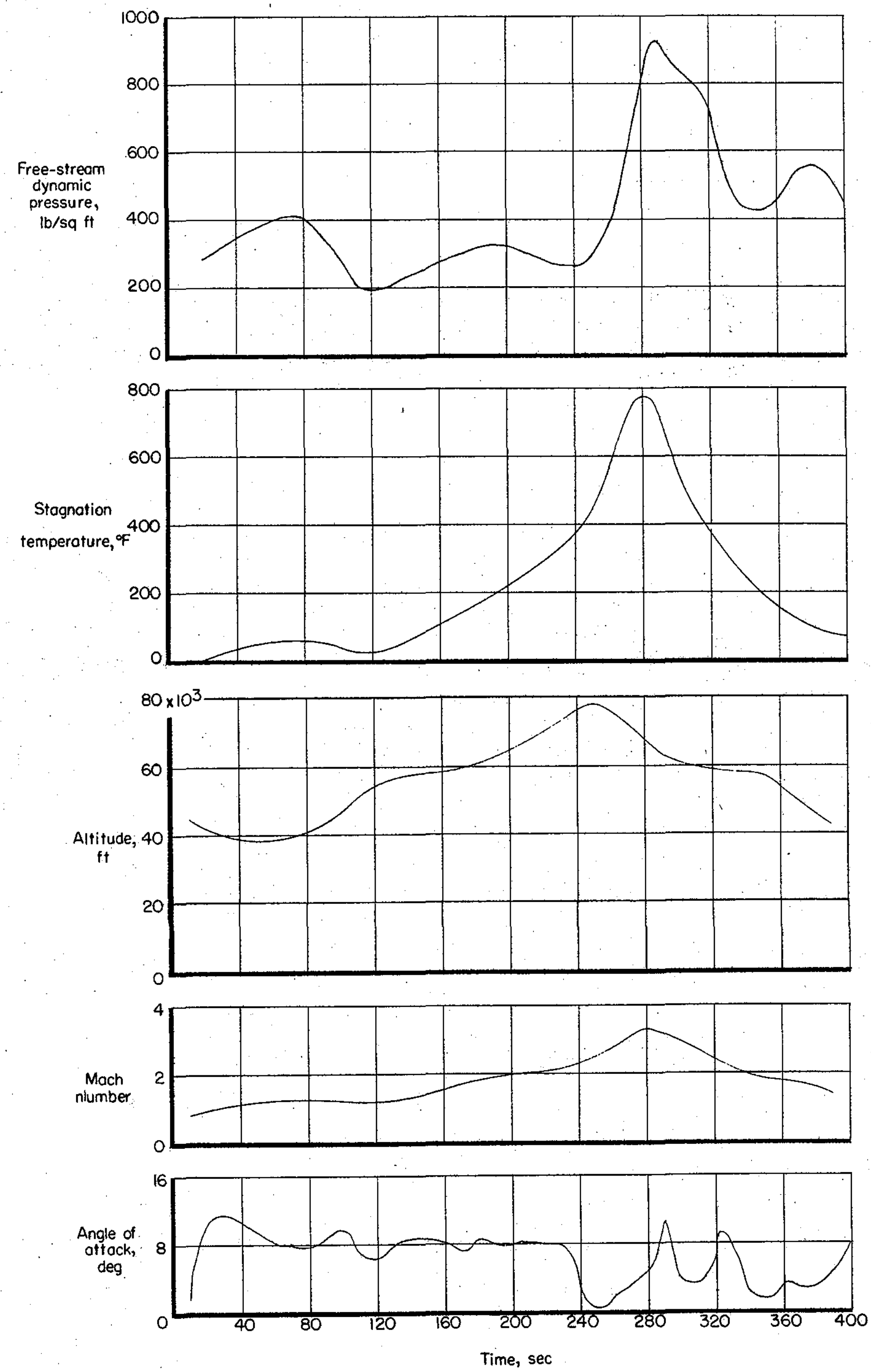

Figure 3.- Time history of X-15 free-stream dynamic pressure, stagnation temperature, altitude, Mach number, and angle of attack.

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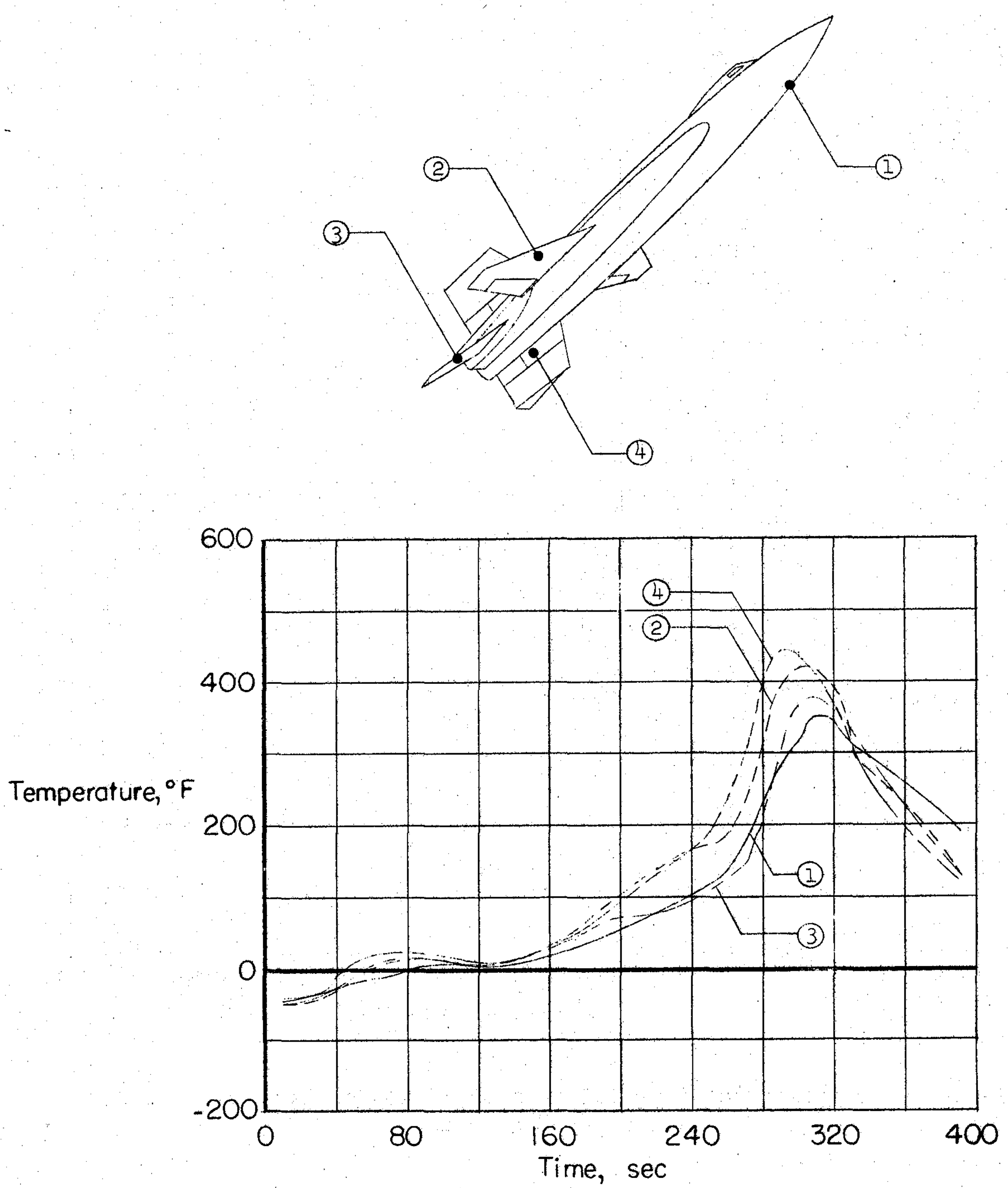

Figure 4.- Time histories of representative X-15 skin temperatures.

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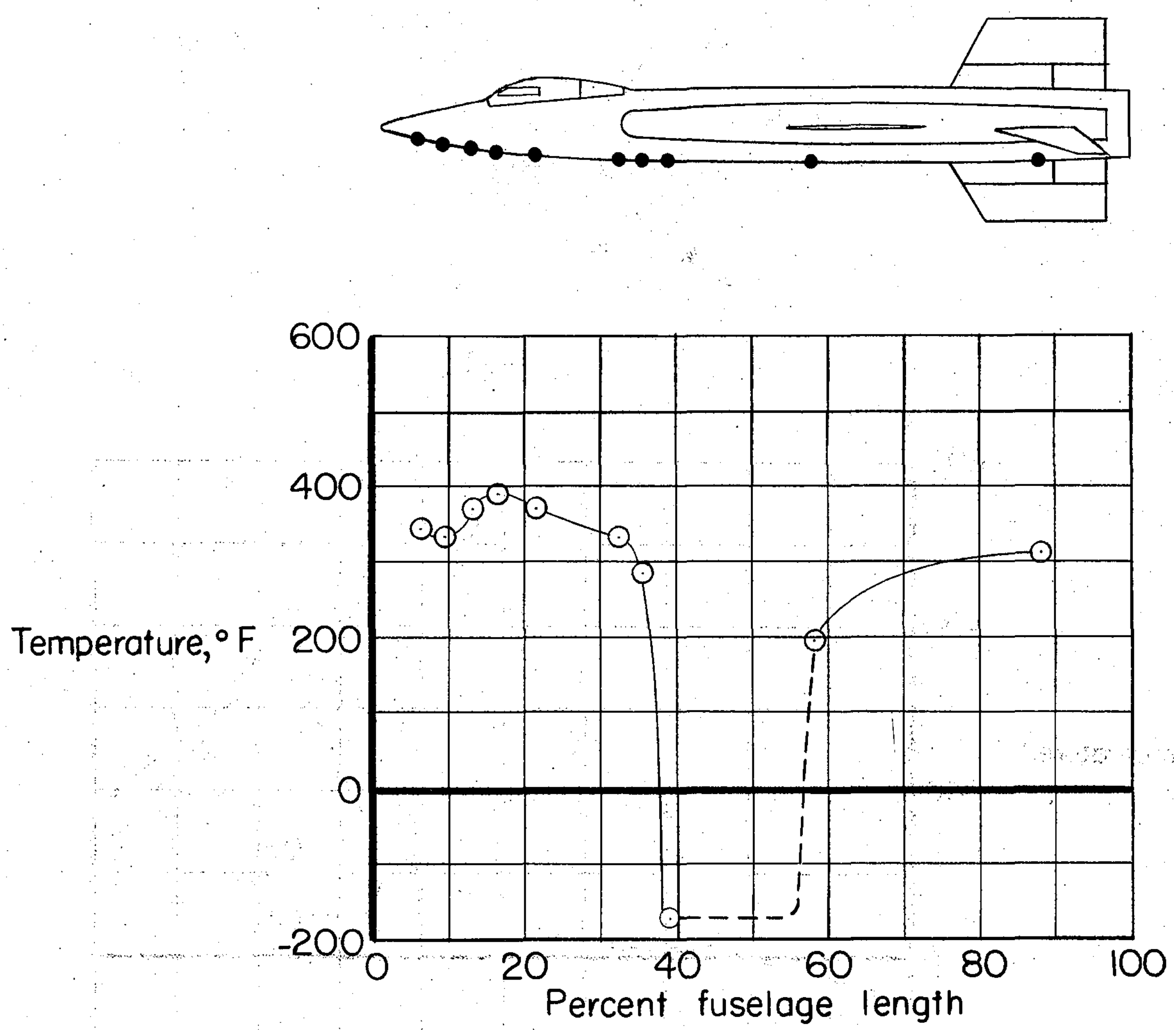

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Figure 5.- Temperature distribution along X-15 fuselage lower skin at time = 308 seconds.

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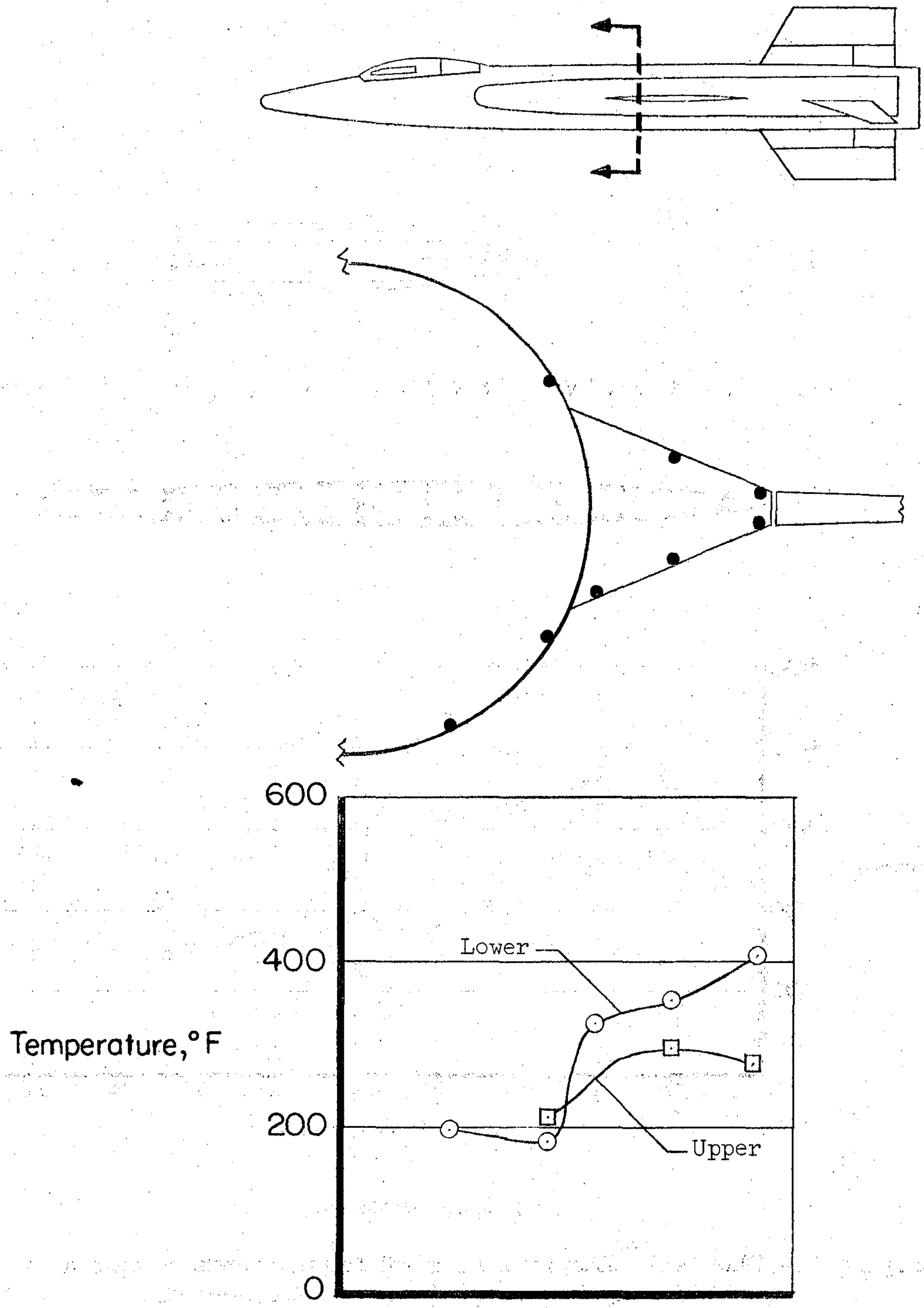

Figure 6.- Lateral distribution of skin temperatures measured on an X-15 fuselage section at time = 308 seconds.

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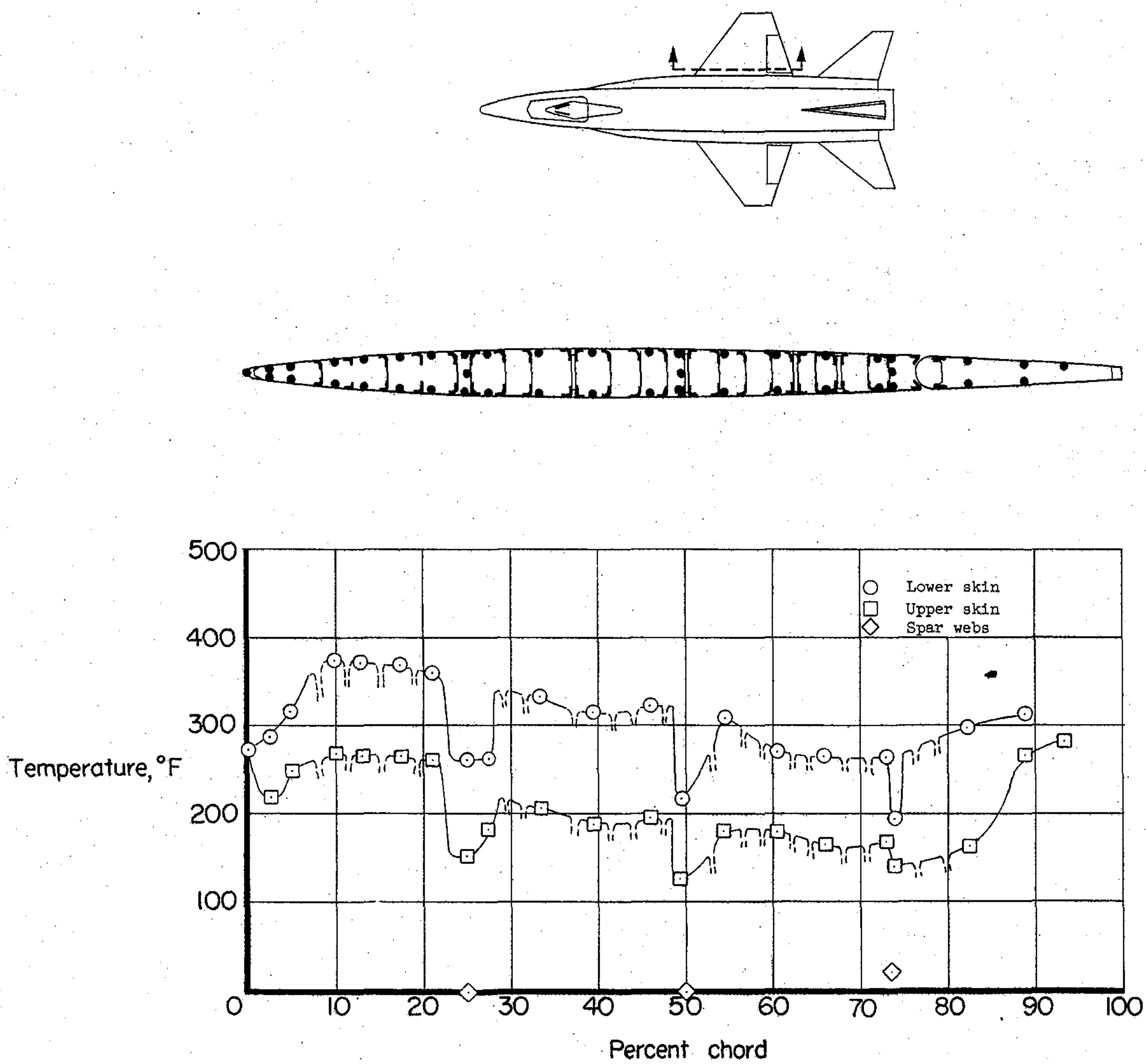

(a) Root section.

Figure 7.- Chordwise distributions of temperatures measured on three X-15 wing sections at time = 308 seconds.

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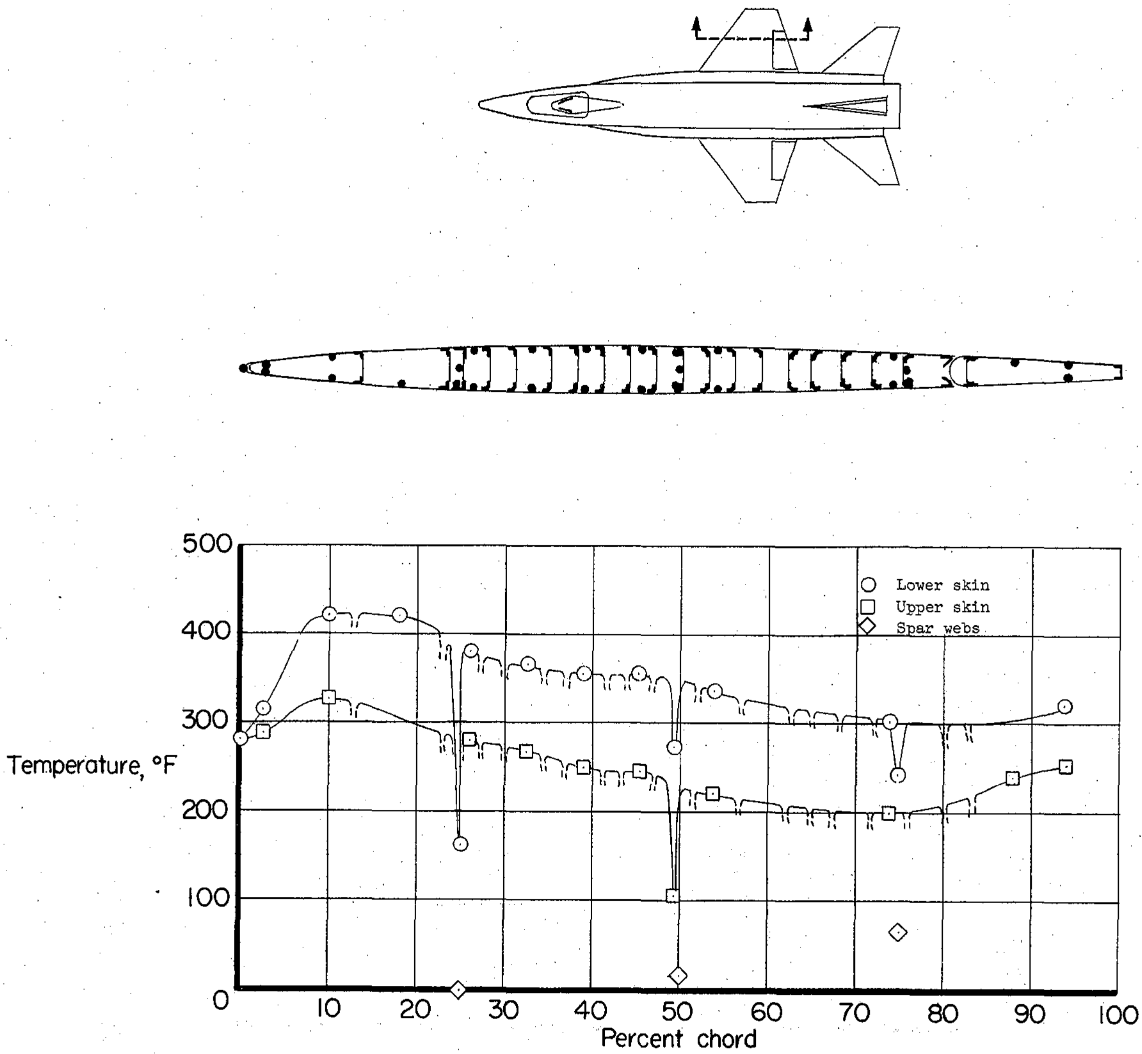

(b) Midsemispan section.

Figure 7.- Continued.

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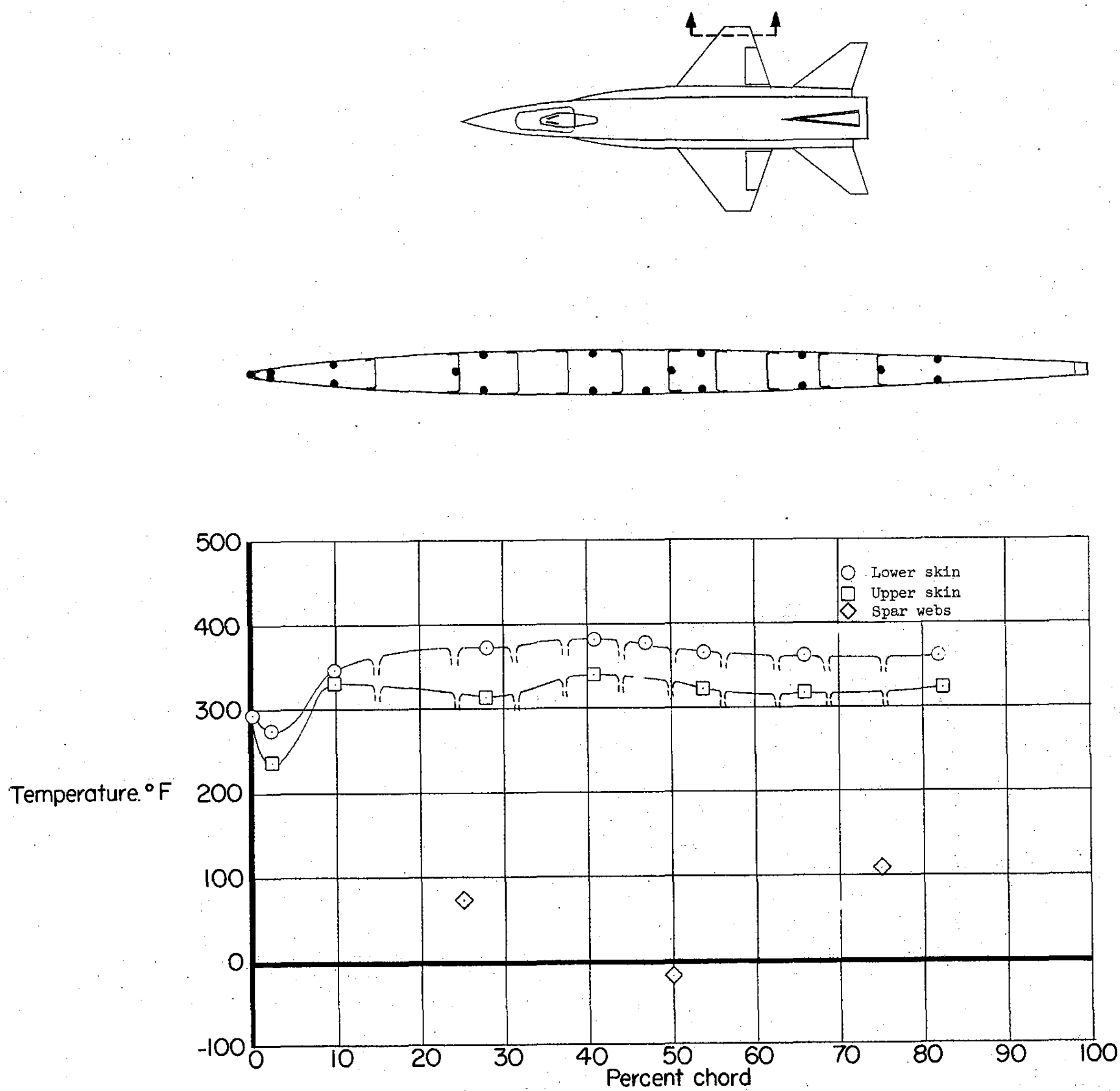

(c) Tip section.

Figure 7.- Concluded.

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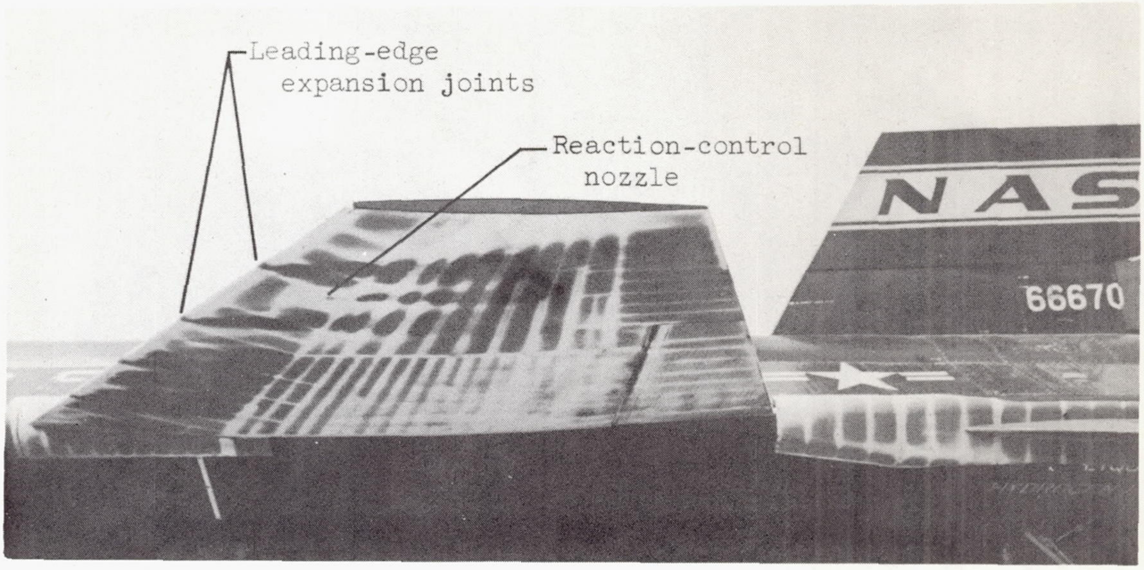
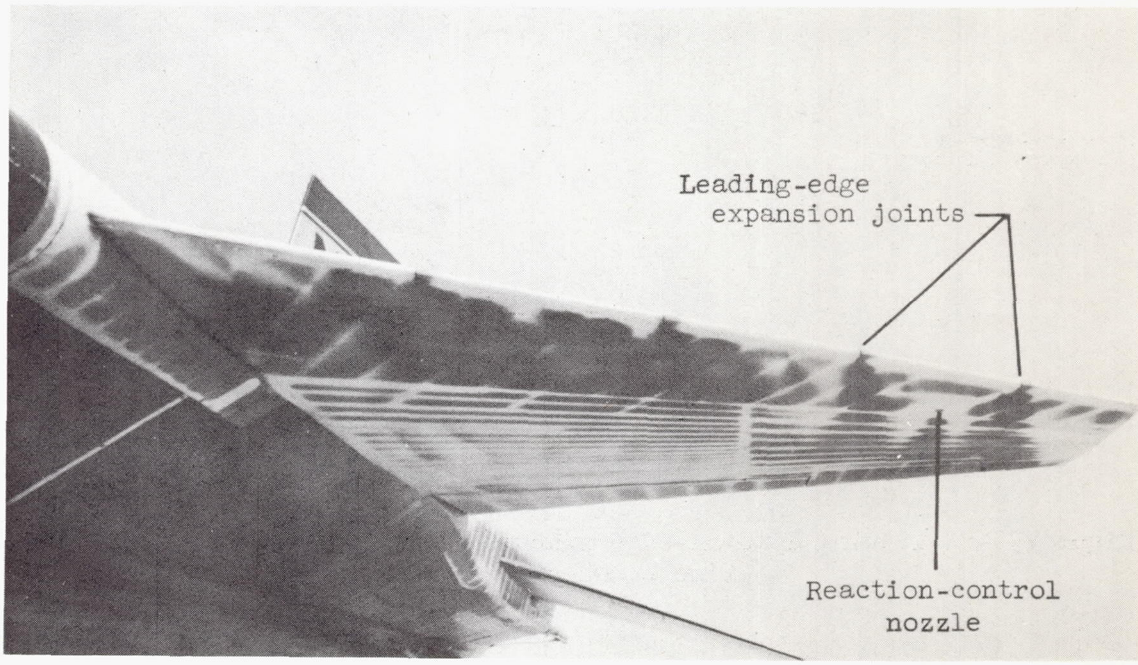


(a) End view. E-5814



(b) Front view. E-5813

Figure 8.- Postflight photograph of temperature-indicating paint on X-15 wing.

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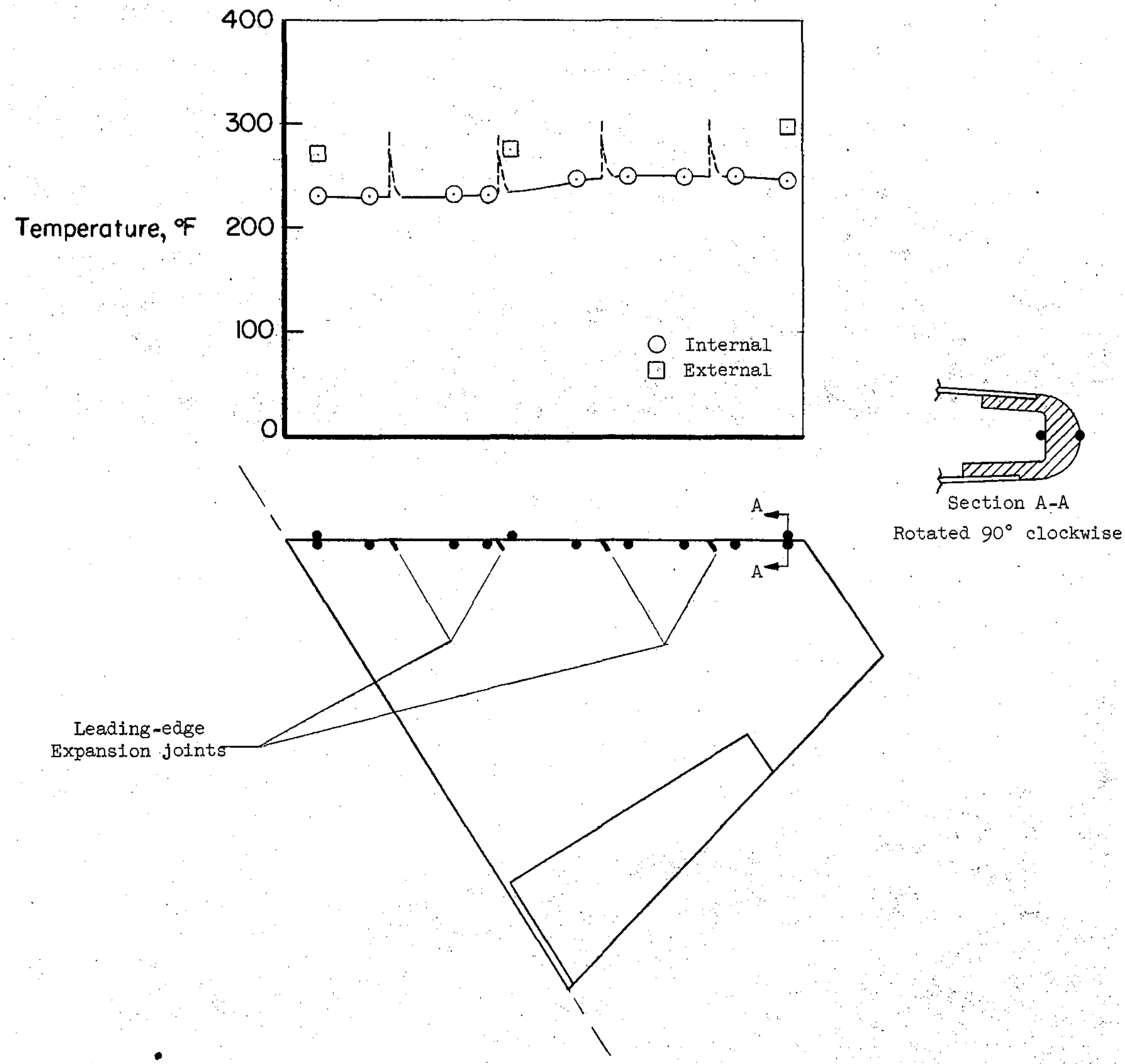

Figure 9.- X-15 wing leading-edge spanwise temperature distribution at time = 308 seconds.

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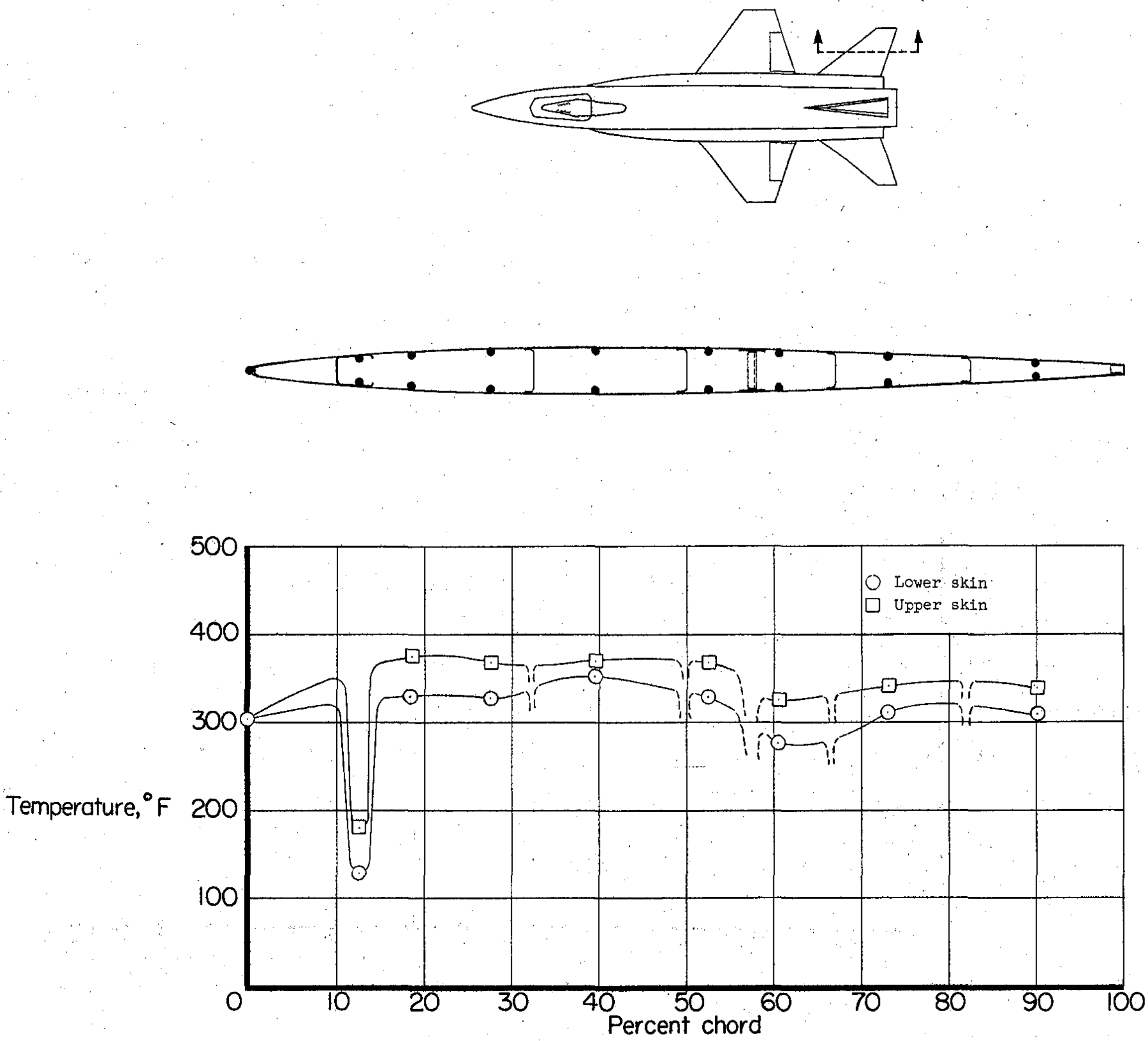

Figure 10.- Chordwise distribution of temperatures measured on a mid-semispan section of the X-15 horizontal tail at time = 308 seconds.

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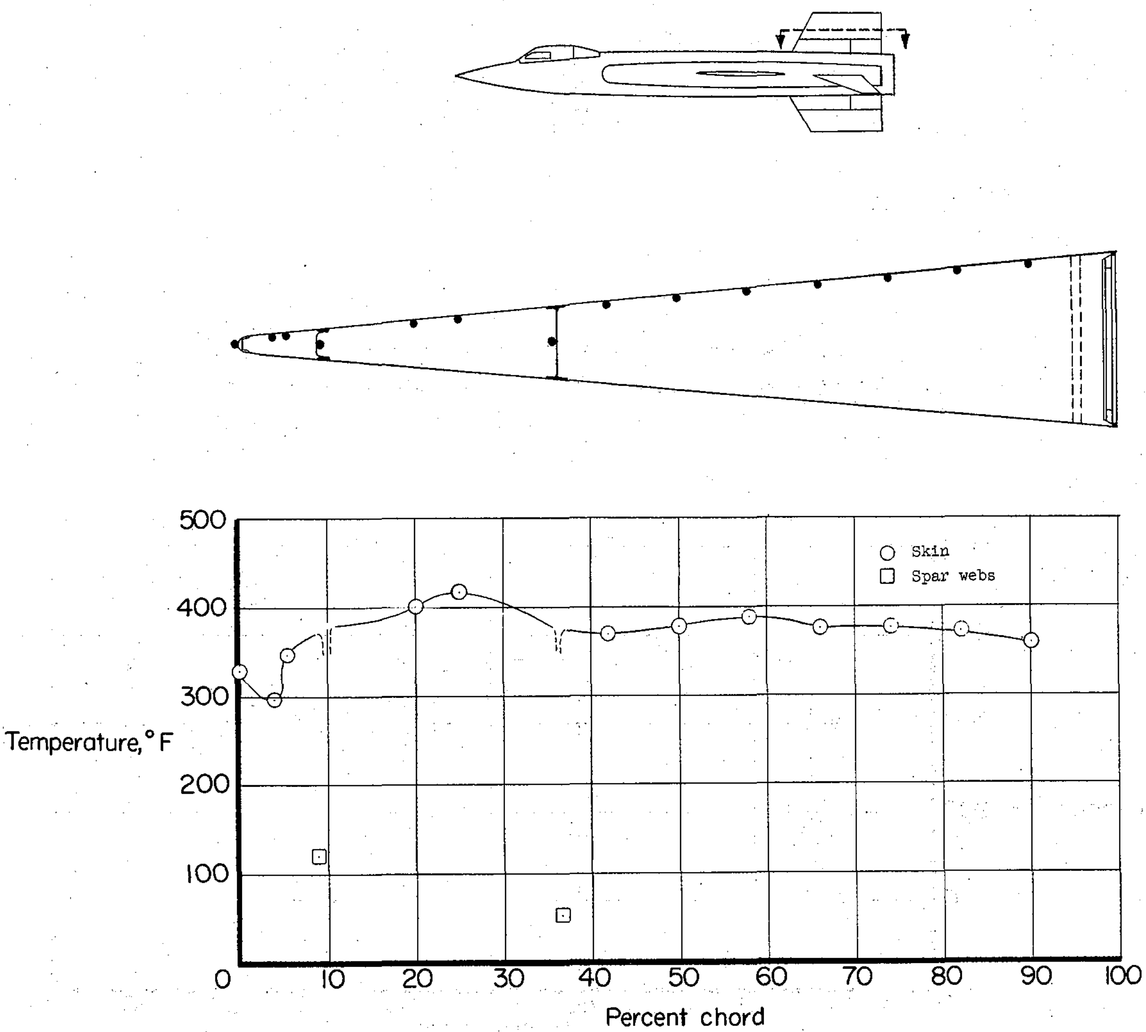

Figure 11.- Chordwise distribution of temperatures measured on a section of the movable portion of the X-15 upper vertical tail at time = 308 seconds.

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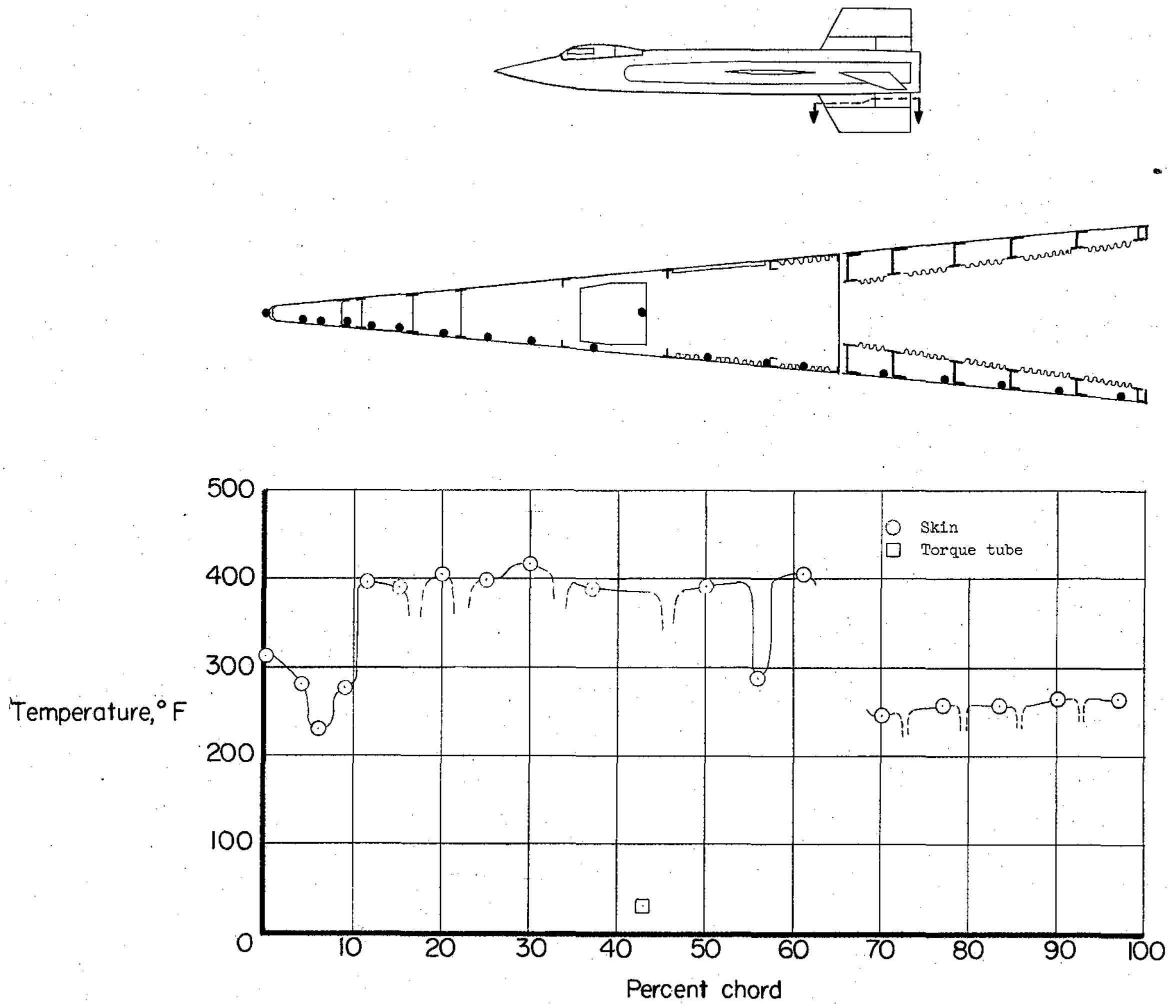

Figure 12.- Chordwise distribution of temperatures measured on a section of the fixed portion of the X-15 lower vertical tail.

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